TECHNICAL NOTE

D-124

STATIC TESTS OF AN EXTERNAL-FLOW JET-AUGMENTED

FLAP TEST BED WITH A TURBOJET ENGINE

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SUMMARY

An exploratory investigation has been conducted on a static test
setup representing an external-flow jet-augmented flap arrangement with
a slotted flap and a turbojet engine. The investigation consisted of
tests in the static condition to determine the turning efficiency of the
flap with several slot entrance configurations for a range of slot-gap
heights with various flattened tailpipes on the turbojet engine.

The results showed that the jet exhaust could be spread out to cover
a reasonably wide section of the flap with a flat nozzle and that, with a
properly selected ramp entrance and gap geometry, jet turning angles
greater than the flap angle and turning efficiency values greater than
90 percent could be attained. The engine exhaust temperatures in the
vicinity of the flap were found to be somewhat lower than the tailpipe
temperature.

INTRODUCTION

The external-flow jet-augmented flap principle has been demonstrated
on small-scale models using cold high-pressure air jets to simulate
engines. (See refs. 1 to 3.) As part of a program to investigate this
principle on a large-scale model with turbojet engines, some exploratory
tests were made with a static test apparatus (zero forward velocity) that
represented a typical arrangement of a pod-mounted jet engine, wing under-
surface, and a slotted trailing-edge flap. In order to induce high cir-
culation lift coefficients in forward flight effectively, the jet flow
must be spread over as wide a portion of the flap span as possible and
turned downward over the flap as efficiently as possible. The purpose
of the exploratory investigation was therefore to determine the extent of
exhaust flow spreading over the flap that could be obtained by altering
the engine tailpipe to produce a flattened jet sheet and to determine
the ability of the slotted flap to redirect the exhaust sheet downward.

Measurements of normal and axial forces, exhaust temperature, and velocity distribution in the jet were obtained for the engine operating with a standard round tailpipe and with three flattened tailpipes for a range of flap-slot heights and slot-entrance ramp angles.

APPARATUS

The jet-augmented flap test setup (shown in fig. 1) simulated the lower surface on an airplane wing with a slotted flap and a pod-mounted engine. For test purposes the representative wing system was inverted in order to keep the engine exhaust from striking the ground and creating a problem of trash ingestion by the engine. The entire engine-wing-flap system was mounted on strain gages to give independent vertical- and horizontal-force measurements for determining the efficiency of the flap in turning the jet sheet. A flat plate was used to represent the wing surface since for these tests it was of interest only to have a surface to deflect the engine exhaust into the flap slot. The flap was attached to the frame with adjustable brackets which allowed variation of the slot-gap opening and the angle of flap deflection. The flap span and chord were 84 inches and 18 inches, respectively. The three flap-slot entrance ramp configurations shown in figure 2 were used in combination with the flap: a straight ramp with a 15° bend with respect to wing surface, a ramp with a 10° bend and a cusp on the trailing edge, and a straight ramp with no bend.

It was desirable to achieve complete coverage of the flap surface with the jet sheet. For this purpose the three tailpipes shown in figure 3 were constructed with width-height ratios of 6.67 (20 inch by 3 inch), 19.72 (36 inch by 1.75 inch), and 60 (60 inch by 1 inch). These tailpipes will hereinafter be referred to according to their width as the 20-inch, 36-inch, and 60-inch tailpipes. The normal round nozzle had an exit area of 59 square inches and this same exit area was maintained in the construction of the flattened versions. The nozzle area of the 36-inch tailpipe was adjusted by inserting wedges in the ends of the nozzle. Because of the simplified method used in the construction of the 20-inch and the 36-inch tailpipes, large internal cross-sectional area expansions occurred; and internal duct losses would be expected to be large for a configuration of this type. The primary objective of the tests reported herein, however, was to study the external-flow characteristics, and the internal losses were considered to be of little importance in this case. The 60-inch tailpipe, as shown by figure 3, consisted of 10 separate tubes leading from the engine annulus to the exit. The total internal area of the tubes equaled that of the engine annulus, and the tubes converged at the exit to the required nozzle exit area of 59 square inches.

TESTS

Preliminary thrust-calibration tests were conducted with the flap removed to determine the basic thrust characteristics of the engine with the standard round tailpipe and the 20-inch, 36-inch, and 60-inch flattened nozzles. These thrust measurements were used as a basis for determining the turning efficiency of the flap. The flap was then installed and the engine was tilted to aline the thrust axis of the engine with the slot gap as shown in figure 4. For a constant gap height and ramp angle it was found in preliminary tests that, for flap angles in the moderate deflection range (30° to 50°), there seemed to be little effect of flap deflection on turning efficiency. A flap deflection of 45° was, therefore, chosen for all the systematic tests discussed in this paper. The turning-efficiency tests were conducted with the standard and flattened tailpipes installed for the three entrance ramp angles shown in figure 2. Horizontal- and vertical-force measurements were obtained, and visual flow surveys were conducted during the turning-efficiency tests for a range of flap-slot heights shown in figure 2.

The engine thrust, fuel flow, and engine speed have been corrected to standard conditions of 29.92 inches of mercury ambient pressure and 59° F ambient temperature by the following equations:

For corrected thrust in pounds,

$$F_{corr} = \frac{F}{\delta}$$

for corrected fuel flow in pounds per hour,

$$W_{f,corr} = \frac{W_f}{\delta \sqrt{\theta}}$$

and for corrected engine speed in revolutions per minute

$$n_{corr} = \frac{n}{\sqrt{\theta}}$$

where

δ ratio of ambient pressure to standard pressure

θ ratio of ambient temperature to standard temperature (519° R)

The turning effectiveness of the flap was determined from the following equations:

For flap turning efficiency,

$$\eta = \frac{F_{r,corr}}{F_{corr}}$$

for angle of resultant-force vector in degrees,

$$\varphi = \tan^{-1} \frac{F_y}{F_x}$$

and resultant force in pounds

$$F_r = \sqrt{(F_x)^2 + (F_y)^2}$$

where

F_x horizontal force, lb

F_y vertical force, lb

Measurements of the velocity distribution of the jet exhaust were obtained from the three flattened tailpipes for a flap deflection of 45° with the 10° cusped ramp and a 3-inch slot gap. The exhaust gas temperatures were measured at a height of 1 inch above the plate at the leading edge of the slot entrance ramp as shown in figure 4.

DISCUSSION

Presentation of Data

Surveys of the exhaust velocity and temperature variation across the jet sheet are shown in figure 5. Figure 6 presents the basic engine thrust calibration with speed for the four tailpipes. The basic data on the horizontal and vertical forces and fuel flows are given in figure 7. The variation of turning efficiency with slot-gap height is shown in figure 8. The force results are summarized in figure 9 in which the resultant forces (turning efficiencies) and the resultant-force-vector angles are presented in terms of the vertical and horizontal forces for a range of flap-slot-gap heights.

External-Flow Characteristics

High values of turning efficiency and jet turning angle are necessary conditions for an effective jet-augmented-flap system; however, it is essential that the jet must spread out over a large part of the span of the deflected flap in order to induce high circulation lift on the wing in forward flight. The results of the flow surveys will therefore be presented and discussed first in order to aid the reader in the evaluation of the force measurements when they are presented later.

The results of flow surveys to determine the extent of jet spreading produced by the 20-inch, 36-inch, and 60-inch flattened tailpipes are

shown in figure 5. As pointed out previously, the velocity distribution and temperatures of the jet shown in figure 5 were obtained for the 10° cusped entrance ramp at a station located at the ramp leading edge. (See fig. 4.) A comparison of the jet widths for the three flattened tailpipes from the velocity profiles of figure 5 shows that the 36-inch and 60-inch tailpipes had the widest distribution. The velocity distributions shown in figure 5 indicate that the width of the jets from these two wider nozzles was about the same at the leading edge of the slot ramp where the survey was made. Visual observations of the flow by means of smoke and tufts, however, showed that, as the flow from the 36-inch tailpipe spread over the flap, it extended well beyond the ends of the flap; whereas the flow from the 60-inch nozzle tended to remain well within the span of the flap. It would therefore be presumed that, if the turning effectiveness were equal, the wider spread flow from the 36-inch nozzle would be more effective in inducing a high circulation lift over a wing in forward flight. The visual observations also indicated that the exhaust from all the tailpipe configurations impinged on the wing surface well ahead of the flap and that, in general, the maximum depth of the jet was about equal to the height of the nozzle exit above the plate. With exception of the 60-inch nozzle the exhaust continued to spread at about the divergent angle of the nozzle after impingement. The exhaust from the 60-inch jet, however, did not spread, apparently because of the small divergent angle of the end nozzles, but flowed straight back to the flap at about the width of the nozzle.

The jet temperatures at the entrance ramp are indicated in figure 5 by the spanwise row of numbers at the 1-inch height station where they were measured. These data show that the exhaust-gas temperatures near the flap were relatively low and had a maximum value of about 400° F as compared with a tailpipe temperature of about 900° F.

Nozzle Calibrations

The thrust values of the various tailpipes presented in figure 6 show, in general, that there were no major differences in the thrust of these tailpipes. These data should not be used for a close quantitative comparison of the effect of tailpipe shape, however, because it is not known that all the engine operating conditions and tailpipe geometry were directly comparable when the engine was running. For example, the fact that the 20-inch nozzle produced more thrust than the round nozzle indicates that there were such differences. In this case the thrust and fuel flow of the 20-inch nozzle were very similar to those for a round nozzle with an area of 61 square inches. It seems likely that the sides of the 20-inch nozzle bowed outward somewhat and gave an increase in area under the heat and pressure experienced when the engine was running. A similar effect in varying degrees might have been experienced with all the rectangular tailpipes depending on their individual construction.

Turning Efficiency

The results of the turning efficiency tests from figure 7 are presented in summary form in figures 8 and 9 for a flap deflection of 45°. The data of figure 9(a) for the 15° ramp (which might be representative of a conventional slotted flap configuration) show that, with the proper gap height, flow turning angles higher than the nominal flap deflection of 45° and efficiency values as large as $\eta = 0.89$ could be obtained. The maximum turning effectiveness was obtained with the 36-inch nozzle which gave an efficiency η of 0.89 and a turning angle of 51° which was greater than the nominal flap deflection of 45°. The poorest turning effectiveness was obtained with the 60-inch tailpipe which gave a maximum efficiency of about 78 percent. Visual observations of the flow on the ramp showed that the flow was separated and indicated that the ramp angle of 15° was too large; better results might be obtained with a different ramp configuration.

The data of figure 9(c) show that, when the ramp angle was reduced to 0°, the values of both φ and η were increased above those for the 15° ramp for all tailpipes except the standard round tailpipe which was not considered to be important since it would probably induce little circulation lift as a jet-augmented-flap arrangement. With this ramp the 36-inch tailpipe again gave the best turning effectiveness.

For practical applications, the zero ramp might not be satisfactory, because both large flap movements and ramp movement would be required to position the flap correctly when deflected. A compromise ramp was tested (10° ramp with cusped trailing edge) and the results are presented in figure 9(b). With this ramp, as with the 0° and 15° ramps, the turning efficiency was greatest with the 36-inch tailpipe. The 10° cusped ramp reduced the turning efficiency of the 36-inch tailpipe, as compared with 0° ramp, but gave a higher efficiency than the 15° ramp.

In general, larger turning angles were obtained with the wider tailpipes. A greater portion of the thin jets produced by the wider tailpipes passed through the slot and down the upper surface of the flap which was at a greater deflection than the nominal deflection of the flap mean line. Most of the jet from the round tailpipe impinged on the lower surface of the flap and was deflected at angles somewhat lower than those for the flattened tailpipes. Of the tailpipes tested, the 36-inch tailpipe generally produced highest turning efficiency, the greatest turning angle for all three ramp configurations; and, as previously pointed out, this tailpipe also produced the widest distribution of the jet over the flap.

CONCLUSIONS

The results of an exploratory static investigation made to determine
the flow characteristics and turning effectiveness of a simulated jet-
augmented-flap configuration with several flattened jet engine tailpipes
and ramp angles indicate the following conclusions:

1. In general, with the proper ramp and flap slot configuration,
the flattened tailpipes spread the jet exhaust effectively and produced
high values of turning angle and turning efficiency.

2. The rectangular (1.75-inch by 36-inch) nozzle effectively
spread the jet exhaust over the entire 84-inch span of the flap.

3. With the 36-inch nozzle it was possible to turn the jet
exhaust about 55° with a flap deflection of 45° and, simultaneously, to
obtain a turning efficiency of 93 percent. The turning efficiency with
this tailpipe was as high as or higher than that of any of the other
tailpipes tested.

4. For the 36-inch tailpipe, the 0° ramp produced the highest
turning efficiency, and the 10° cusped ramp and the 15° ramp gave, respec-
tively, lower values.

5. The temperature of the jet exhaust in the vicinity of the flap
was only about 400° F - a notable reduction from the 900° F tailpipe
temperature.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Field, Va., August 11, 1959.

REFERENCES

1. Campbell, John P., and Johnson, Joseph L., Jr.: Wind-Tunnel Investigation of an External-Flow Jet-Augmented Slotted Flap Suitable for Application to Airplanes With Pod-Mounted Jet Engines. NACA TN 3898, 1956.

2. Johnson, Joseph L., Jr.: Wind-Tunnel Investigation at Low Speeds of Flight Characteristics of a Sweptback-Wing Jet-Transport Airplane Model Equipped With an External-Flow Jet-Augmented Slotted Flap. NACA TN 4255, 1958.

3. Davenport, Edwin E.: Wind-Tunnel Investigation of External-Flow Jet-Augmented Double Slotted Flaps on a Rectangular Wing at an Angle of Attack of 0° to High Momentum Coefficients. NACA TN 4079, 1957.
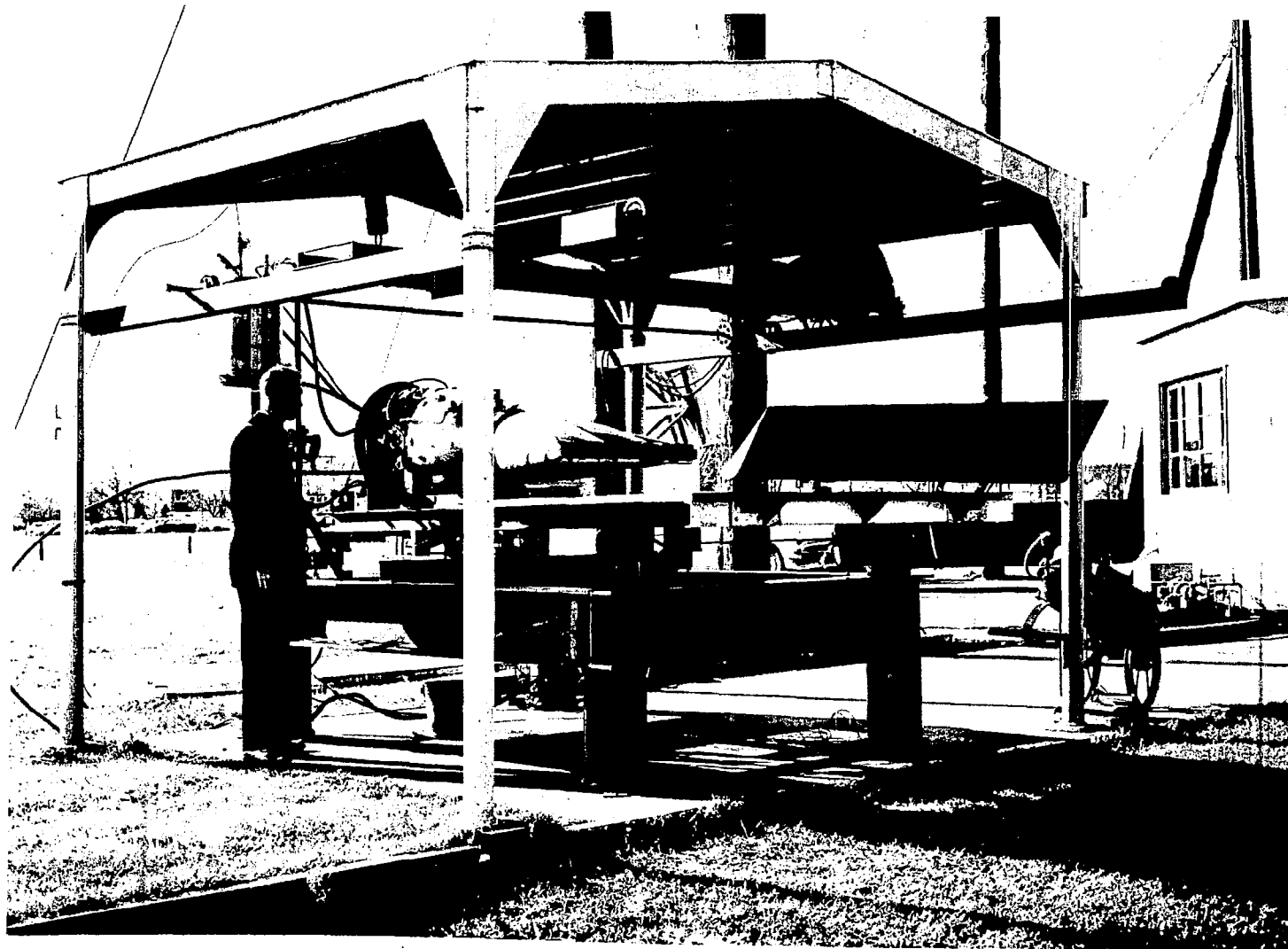
Figure 1.- General view of jet-flap test apparatus.   L-57-4916
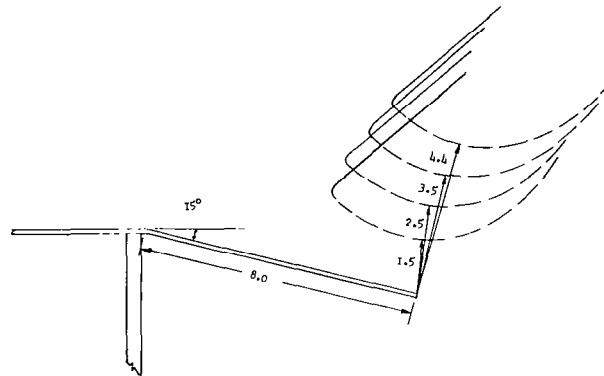
(a) 15° ramp.
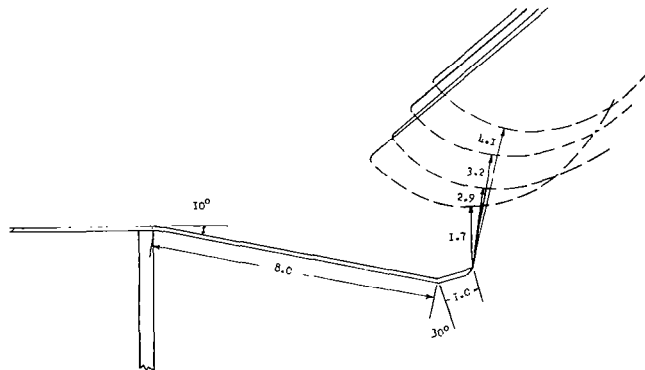
(b) 10° cusped ramp.
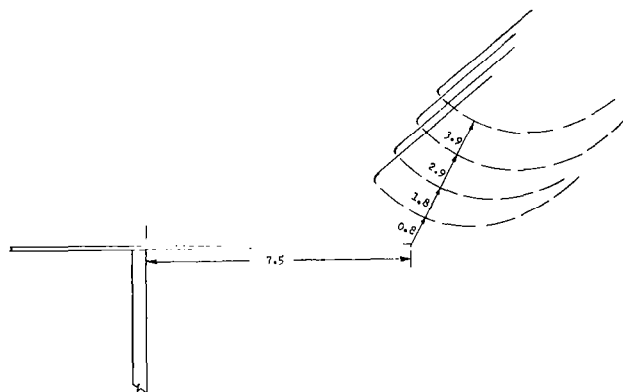
(c) 0° ramp.

Figure 2.- Typical cross section showing flap slot and ramp geometry.
All dimensions are in inches.
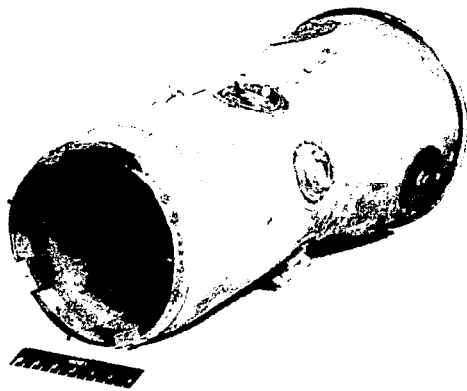
Round tailpipe
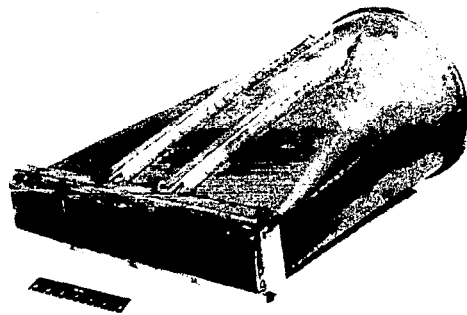
3×20 tailpipe
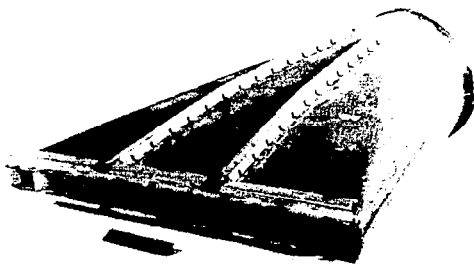
I.75×36 tailpipe

I×60 tailpipe

L-59-5050

Figure 3.- Photographs of the original and modified tailpipes.

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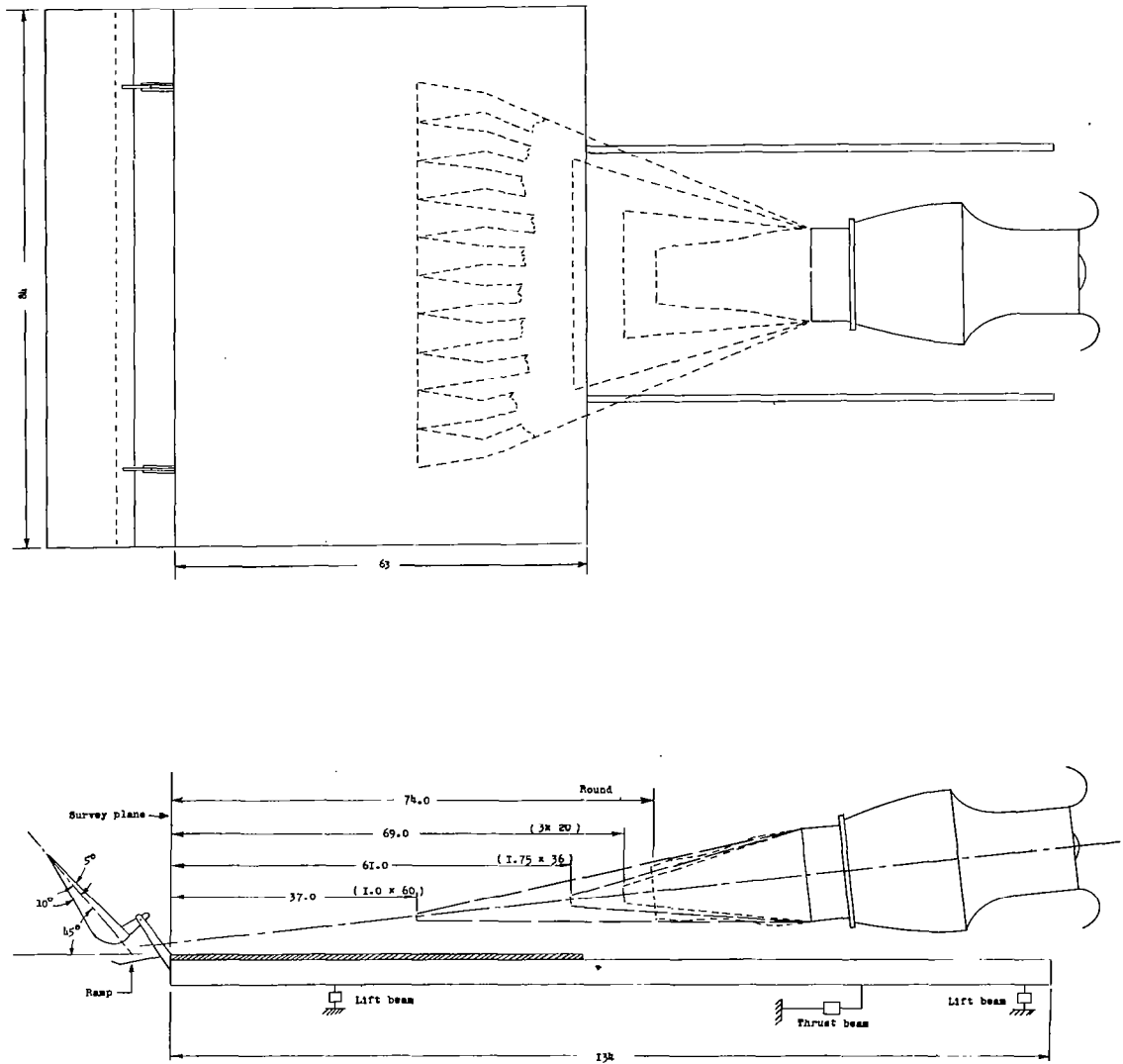
Figure 4.- Geometric relationship of the various tailpipes to the flap
slot. All dimensions are in inches.
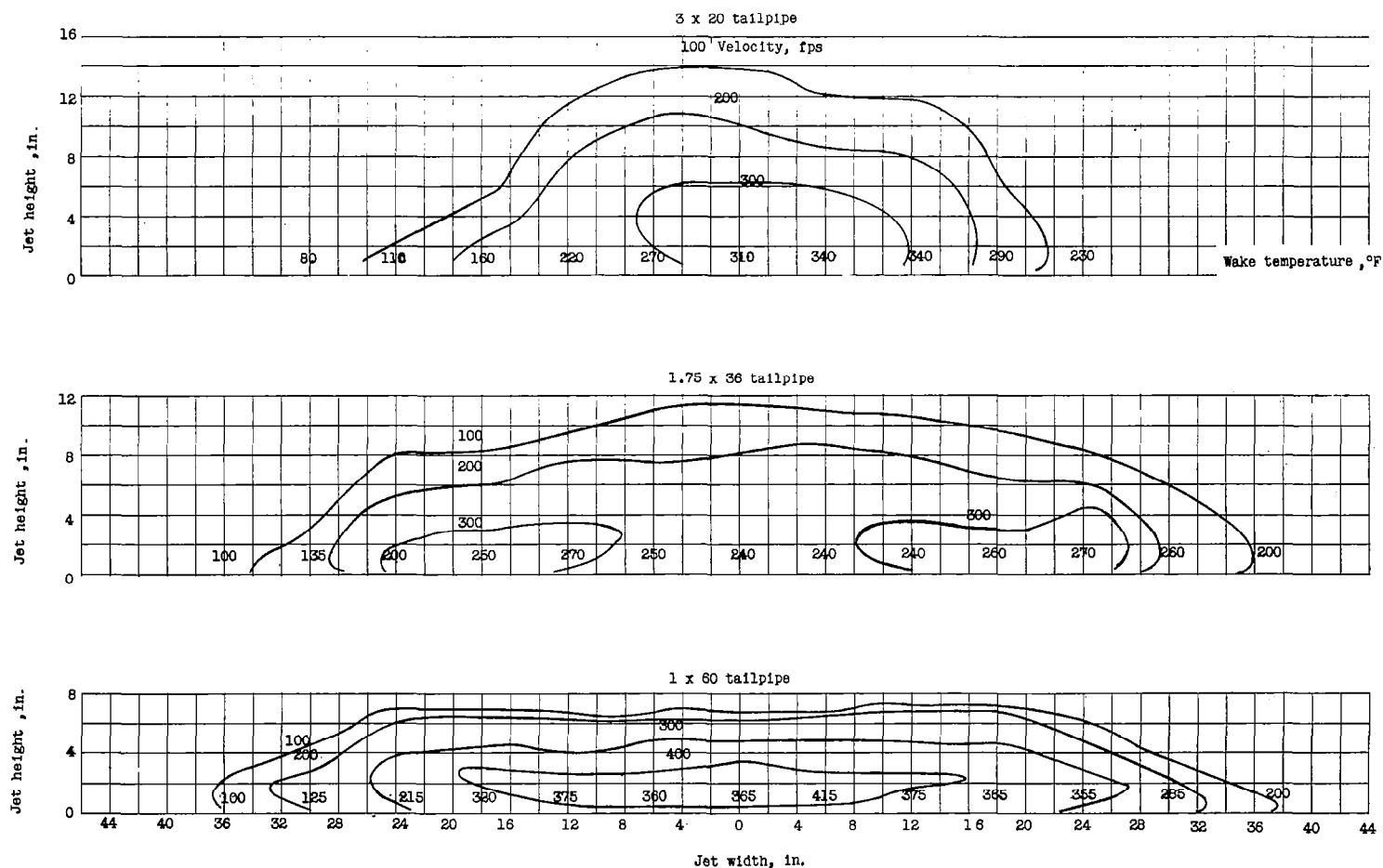
Figure 5.- Jet velocity and temperature distribution at the leading edge of the slot entrance ramp for the 10° cusped ramp with a 3-inch gap. Tailpipe temperature approximately 900°.
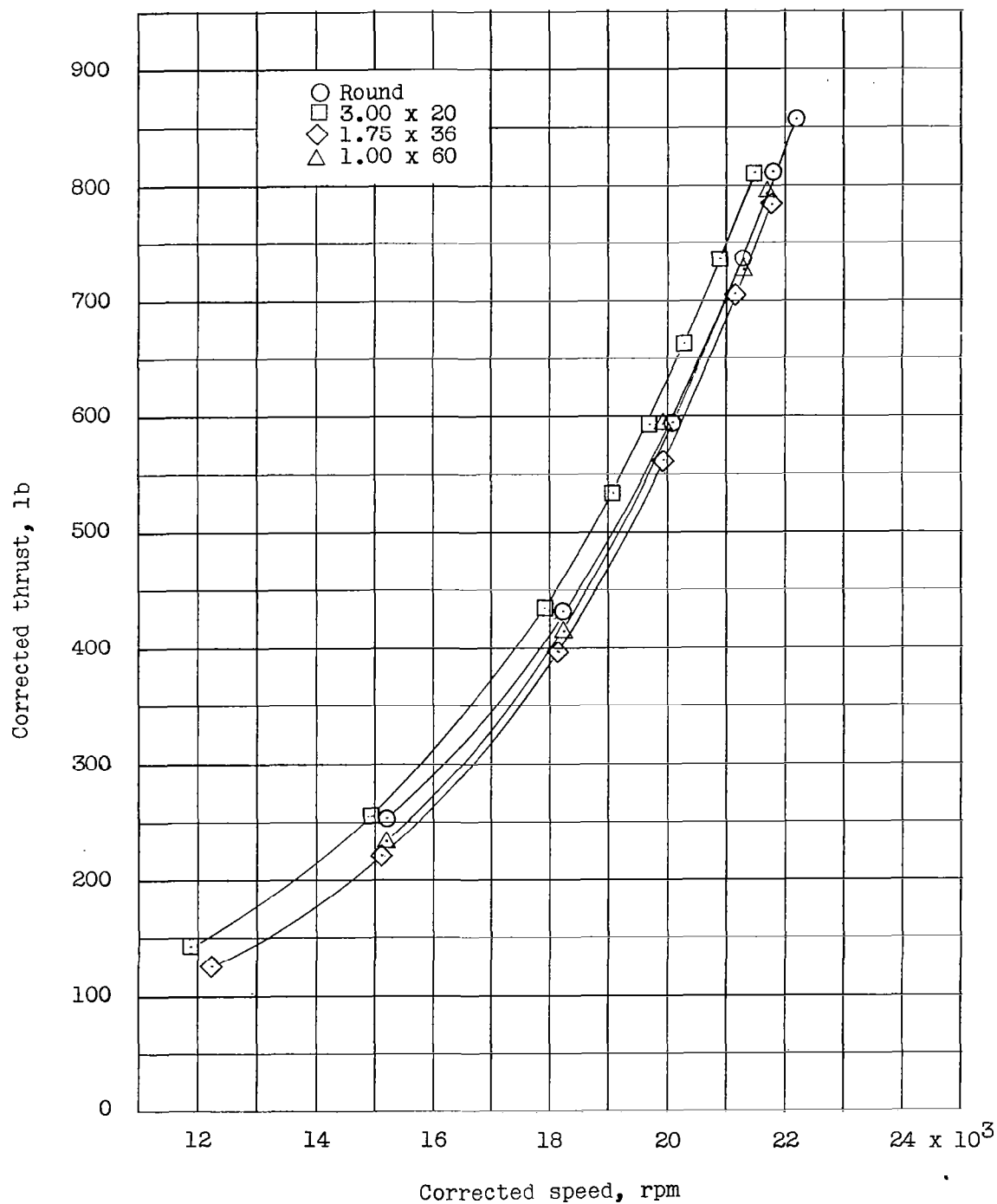
Figure 6.- Variation of engine thrust with engine speed.
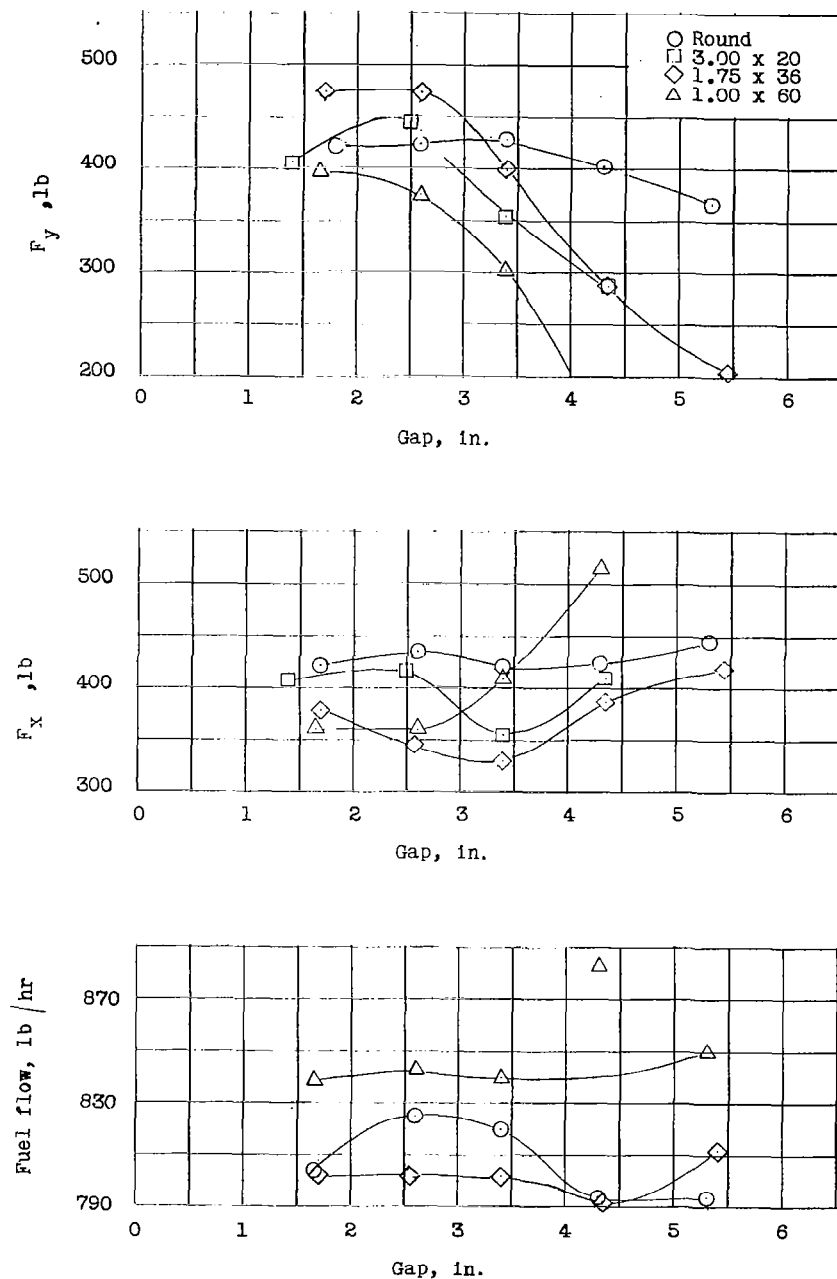
(a) 15° ramp.

Figure 7.- Variation of vertical and horizontal forces and fuel flow
with slot-gap height for the several tailpipe configurations at
constant engine speed.
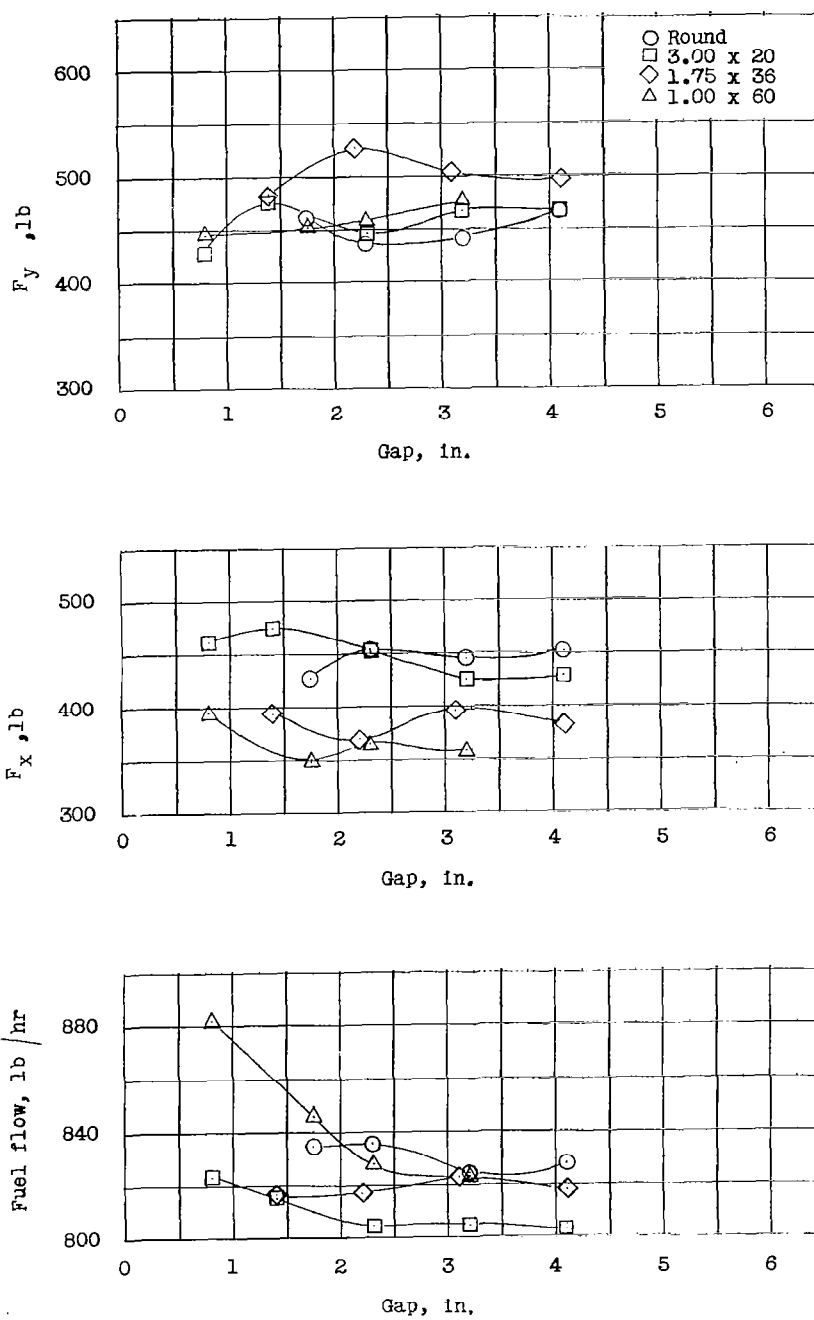
(b) 10° cusped ramp.
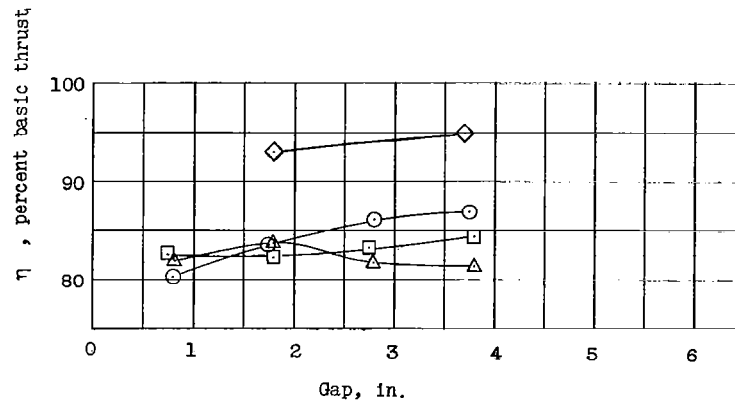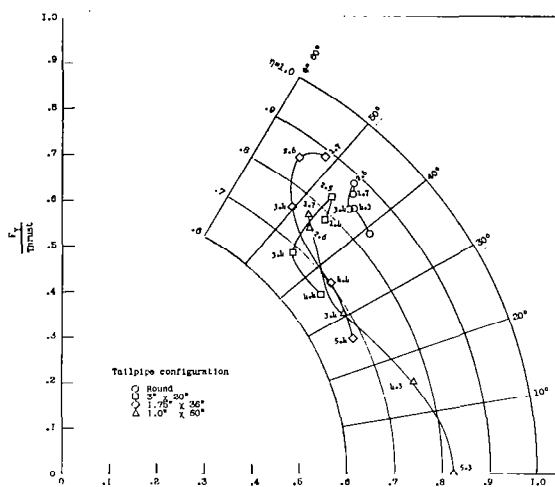
Figure 7.- Continued.
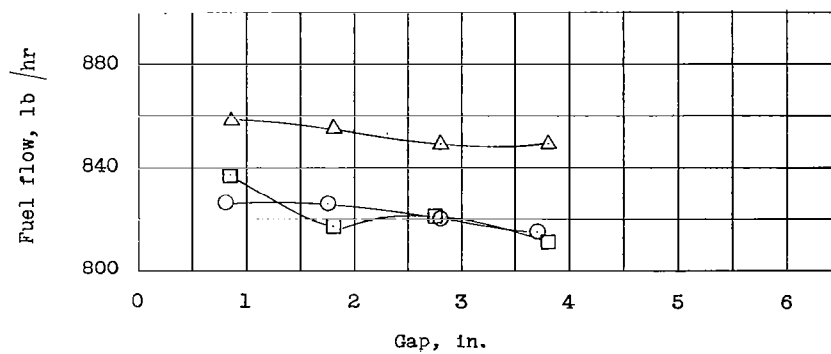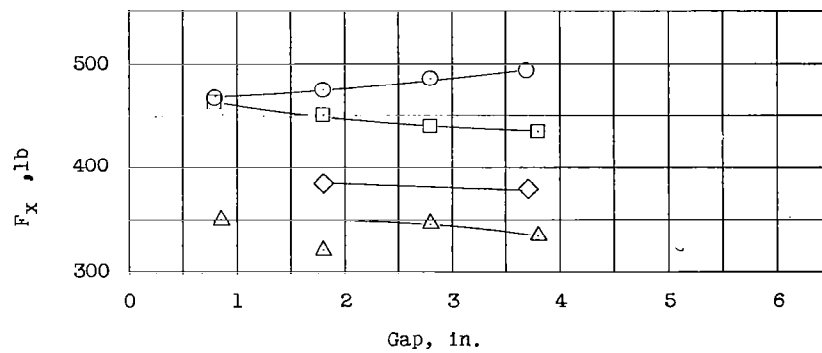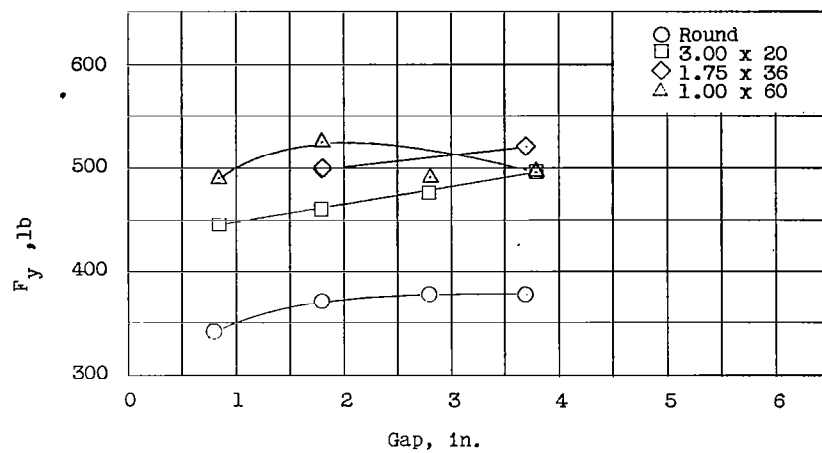
(c) 0° ramp.

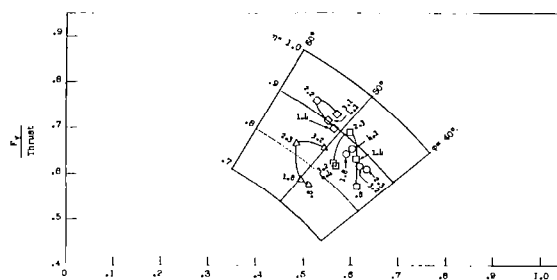Figure 7.- Concluded.

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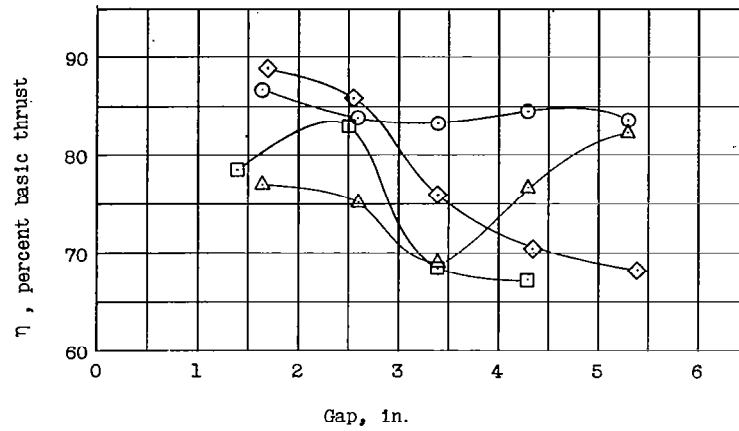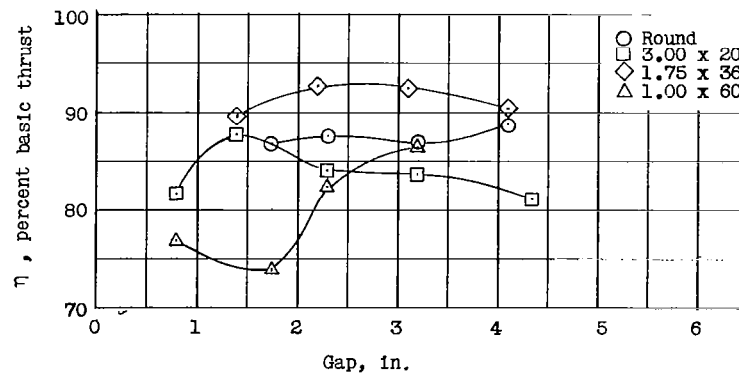
(a) 15° ramp.
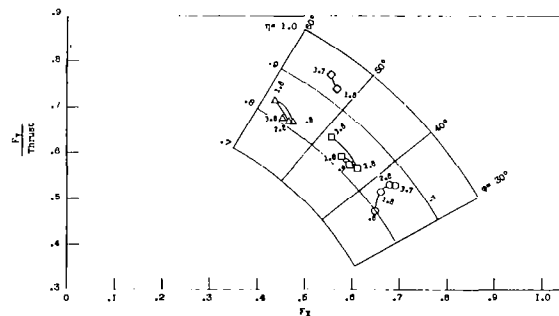

(b) 10° ramp.

(c) 0° ramp.

Figure 8.- Variation of flap turning efficiency η with flap-slot-gap height for several slot-ramp angles and tailpipe modifications.

(a) 15° ramp.

(b) 10° cusped ramp.

(c) 0° ramp.

Figure 9.- Summary of turning efficiency η and turning angle φ. Numbers by symbols represent gap height in inches.